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14. ABSTRACT

The objective of this study was to compare the occurrence of simulator sickness symptoms while participants wore either a virtual reality (VR) or augmented reality (AR) headset. A secondary objective involved comparing how symptoms were impacted by physical motion. Questions remain about how VR and AR impact users with respect to motion sickness. Additionally, it is unknown if there are differences between use in stationary versus mobile environments, the latter being especially important for military applications. During a simulation, participants wore VR and AR headsets while standing on a motion platform and firing at hostile ships under three motion conditions: No Motion; Synchronous Motion, in which the physical and displayed motion were coupled; and Asynchronous Motion, in which the physical motion did not match the display. Symptoms increased over time but were not different with respect to headset or motion. Motion significantly impacted behavioral performance. The VR condition had higher accuracy and faster response time to the commence fire instruction.

15. SUBJECT TERMS

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Comparison of Virtual Reality and Augmented Reality: Safety and Effectiveness

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NOTICES

Disclaimer
The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government.

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The study protocol was approved by the Wright-Patterson Air Force Base Institutional Review Board in compliance with all applicable federal regulations governing the protection of human subjects.

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The study protocol (NAMRUD.2017.0005) was approved by the Naval Medical Research Unit Dayton Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects.

Abstract

(245/250 words)

Objective: The objective of this study was to compare the occurrence of simulator sickness symptoms while participants wore either a virtual reality (VR) or augmented reality (AR) headset. A secondary objective involved comparing how symptoms were impacted by physical motion.

Background: VR and AR technologies are increasingly adopted for many applications; however, questions remain about how they impact users with respect to motion sickness. Additionally, it is unknown if there are differences between use in stationary versus mobile environments, the latter being especially important for military applications.

Method: During a simulation, participants wore VR and AR headsets while standing on a motion platform and firing at hostile ships under three motion conditions: No Motion; Synchronous Motion, in which the physical and displayed motion were coupled; and Asynchronous Motion, in which the physical motion did not match the display.

Results: Symptoms increased over time but were not different with respect to headset or motion. Motion significantly impacted behavioral performance. The VR condition had higher accuracy and faster response time to the commence fire instruction.

Conclusion: Wearing a VR or AR headset does not exacerbate motion sickness. The mismatch between visual and vestibular motion does not lead to increased sickness or performance reductions beyond those of motion alone. Further research is necessary to determine if this holds under more extreme motion conditions.

Application: The use of VR or AR headsets for training under gentle motion conditions is practicable and should be permissible under normal conditions during deployment.

Keywords: Virtual Environments, Motion Sickness, Simulation and Training, Attentional Processes, Perceptual-motor Performance

Précis: (48/50 words) Virtual and Augmented Reality headsets were tested under motion conditions to determine any differences in their propensity to cause simulator sickness. They did not differ; however, participants were more accurate and had faster response times to a fire instruction during a shooting task while wearing a VR headset.

Introduction

Virtual reality and augmented reality (VR and AR, respectively) systems offer unique opportunities to enhance operational and training environments. The portability and customizability of these systems make them suitable for use by professionals in a variety of fields. Reduced costs and significant advancements in mixed reality technologies have led to greater adoption of these devices, which raises a host of questions regarding their effects on users and their effectiveness in different environments. One such question is whether there are fundamental differences between the systems in terms of their propensity to cause nausea, eyestrain, or headache. While it is known that VR displays can cause people to feel these symptoms (Draper, Viirre, Gawron, & Furness, 2001; Patterson Winterbottom, & Pierce, 2006), it is not known how AR might differ and what the effects of coupling motion with the virtual environment might be. The answer to these questions is increasingly relevant as these technologies become more widespread and used in more complex simulations that involve motion. For example, people may wear AR headsets while driving to provide navigational guidance, or they might use mixed reality platforms to simulate high risk aerial maneuvers in a safe environment (e.g., Geyer & Biggs, 2018).

Motion-based scenarios are important for military applications because most military-relevant scenarios replicated with mixed reality are likely to have real-world corollaries that involve motion. Naval training scenarios are relevant because performance aboard ship is always going to incorporate motion that varies with the ship type and sea state. Additionally, there are significant concerns involving VR and AR platforms aboard ship because the physical motion experienced is unlikely to be synchronized with motion in the simulation. Other military-relevant applications include firing weapons from a mounted platform on a vehicle or trying to perform tasks in the back of a cargo plane or helicopter. Military applications represent a significant opportunity to explore novel training uses for VR and AR by creating a highly immersive, yet risk free, training environment for high-risk scenarios-.

Mixed reality labels are inconsistent in the literature so we will provide clarity regarding our descriptions. VR refers to an immersive multimedia that simulates a physical presence in entirely virtual environments. AR refers to a display that blends computer-generated and real-world elements to create a hybrid environment, which in this case, may be referred to as augmented virtuality (Milgram & Kishino, 1994), but for the sake of consistency, we will refer to it as augmented reality. Regarding symptomology, there is a debate about the differences between cybersickness, simulator sickness, and motion sickness (Lawson, 2014). For simplicity, we will refer to symptoms related to the combination of motion and either VR or AR as simulator sickness.

The current study used a within subjects 2 (AR vs VR) x 3 (No Motion, Synchronous Motion, Asynchronous Motion) design to examine how VR and AR technologies interact with motion to impact simulator sickness symptom severity. Participants wore the HTC Vive (HTC Corporation; Bellevue, Washington) in the VR condition, and the Microsoft HoloLens (Microsoft Corporation; Redmond, Washington) in the AR condition. In the VR condition, the environment and instructions were contained in the headset. In the AR condition, the environment was projected onto screens and the instructions were communicated through the headset. The AR approach blends computer-generated elements of the heads-up display with elements from the physical surroundings, although these surrounding items were projected onto screens. Both VR and AR scenarios involved the same task, which required participants to destroy hostile ships by aiming a mock M2 Browning .50 caliber machine gun and pressing a button on the controller to fire while aboard a simulated Navy ship. The task is based on a Navy research project, GunnAR, which is a VR/AR Navy technology prototype developed to provide visual instructions from a gunnery liaison officer (GLO) on a heads-up display to a sailor manning a machine gun. Traditionally, this job is done in a very noisy environment, which reduces the effectiveness of verbal orders; using mixed reality technologies allows for more efficient communication across personnel by presenting orders visually in stressful, high consequence environments.

Motion was manipulated to determine whether motion would interact with symptom severity and to explore the possibility of integrating these simulation technologies into moving environments, such as aboard ship during deployment. There were three motion conditions: A No Motion condition, to obtain a baseline measure of simulator sickness due to wearing the headsets and shot accuracy. A Synchronous Motion condition, in which the presented visual motion was the same as the platform motion. This condition was predicted to elicit more simulator sickness than the No Motion condition due to the addition of physical motion. An Asynchronous Motion condition, in which the visual motion and platform motion were intentionally decoupled, was included to assess changes in symptomology when visual motion did not match physical motion. As such, the Asynchronous condition is a critical assessment of the feasibility of using this technology onboard ship, where visual and experienced motion will differ. If the increase in sickness is too great, the benefits of being able to train may be outweighed by the costs of additional sickness or participants' reluctance to use the device. It is also critical to assess if sickness is correlated with behavioral performance. This can be assessed by comparing shot accuracy as a function of condition.

The three objectives of this study were to: 1) determine if there are differences in the type and severity of simulator sickness symptoms from using a VR versus AR headset; 2) measure the impact of physical motion on symptom severity; and 3) determine behavioral performance differences between VR and AR headsets due to factors such as cue salience or signal integration. We hypothesized that physical motion would increase symptom severity, and that the Asynchronous condition would have a greater impact than the Synchronous condition. We did not have any specific hypotheses with respect to differences between the impact of VR or AR on symptoms or performance differences. Taken together, the results can help inform whether these VR and AR programs are capable of being used safely and effectively in moving environments with a particular emphasis on using these technologies aboard ship.

Methods

Participants

An *a priori* power analysis with a medium effect size (f = .30), revealed that 12 participants were required to ensure an observed power of .86 with alpha set at the .05 level. These values were determined by using the G*Power program (Faul, Erdfelder, Lang, & Buchner, 2007). The study protocol was approved by the Naval Medical Research Unit Dayton Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human participants. Fourteen people (3 Female) were recruited from active duty military members and those covered by Department of Defense insurance at Wright-Patterson Air Force Base. Participants were between the ages of 20 and 41 years old (M = 30.17, SE = 1.98). During an initial screening, they answered a preliminary questionnaire to ensure they did not have any conditions (inner ear disorder, temporary illness, etc.) that could be exacerbated by simulator sickness. Participants were also informed that in order to maintain eligibility, they must refrain from drinking alcohol or taking any medication that could affect balance, inner-ear fluid levels, or cause dizziness or lightheadedness for 24 hours before participation. Female participants were administered a pregnancy test prior to experimental sessions to ensure that pregnancy-related nausea would not affect results. One participant discontinued participation after the first session due to boredom, and one participant changed duty station prior to completing the study, leaving 12 in the final sample.

Equipment and Materials

The experiment utilized a within-subjects design, with each participant completing all conditions of the experiment; order was counterbalanced to control for any confounding effects of order and/or practice. For the VR condition, participants wore an HTC Vive headset that displayed a virtual environment created in Unity (Version 5.4; Figure 1). The display resolution was 1080 x 1200 per eye, covered approximately 110° field of vision, and its refresh rate was 90 Hz. Both the environment and onscreen commands (destructive fire, cease fire) were displayed in the headset. For the AR condition, the environment was projected onto three screens that measured 65 in x 48.5 in (165.1 cm x 123.2 cm) each. The screens were joined at approximately 45° angles and were placed close enough to the platform to subtend approximately 110° of the participant’s field of vision, approximately 10 ft (3 m) away from the participant (see Figure 2). Onscreen commands were displayed via Microsoft Hololens, which projects a 2.3 megapixel widescreen display in front of the user.

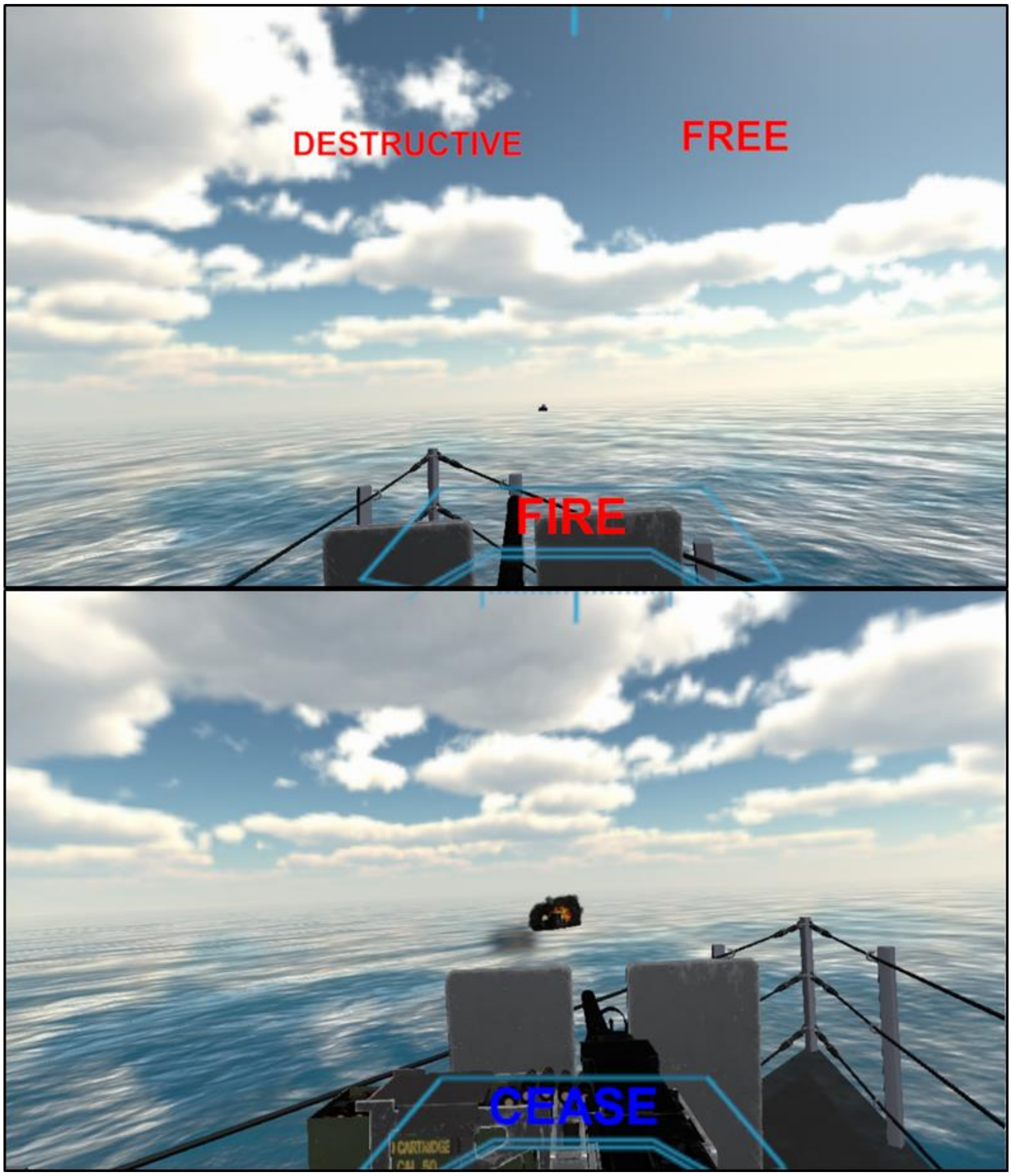

Figure 1. GunnAR virtual environment in which the experiment took place depicting FIRE (top) and CEASE instruction with destroyed hostile ship (bottom). Instructions appeared in red and blue font within the visual display for the VR condition and within the heads-up display for the AR condition. Commence fire instructions presented with red blinking text, whereas cease fire instructions presented with blue blinking text.

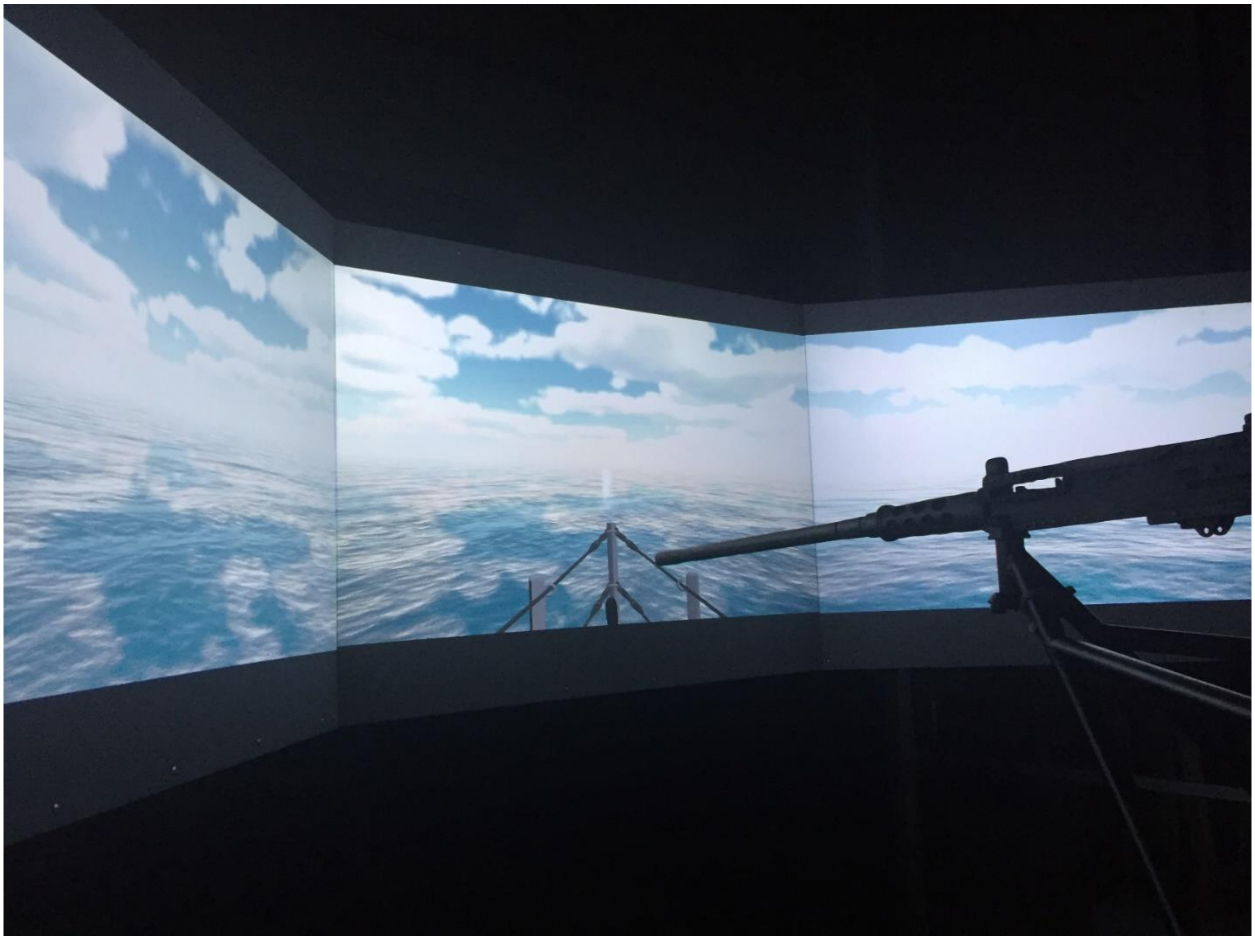

Figure 2. Screen set up for the AR sessions of the experiment.

Within the VR and AR conditions, there were three motion conditions: No Motion, Synchronous, and Asynchronous. In the No Motion condition, the platform did not move. In the Synchronous condition, the motion platform's movement matched the visual display. In the Asynchronous condition, the motion of the platform was intentionally decoupled from the visual display by introducing a 10 second delay between the simulated visual and platform motion. This delay prevented the current motion in the visual display from matching the physical motion of the platform, and the 10 second lag was arguably sufficient to prevent the participant from being able to anticipate upcoming motion. Each experimental session consisted of two fifteen-minute motion profiles. Motion stopped between profiles long enough to verbally administer a sickness questionnaire, which took approximately one minute.

Motion was conveyed through a six degree of freedom Stewart platform with x, y, z, yaw, pitch, and roll axes; however, for this experiment, only the yaw, pitch, and roll axes were used. Thus, the motion of the platform mainly consisted of roll and pitch perturbations. Mean roll frequency was 0.143 Hz, and mean pitch frequency was 0.058 Hz. The motion was relatively gentle and similar to what one would experience on an Arleigh-Burke class destroyer in calm seas. The platform was covered with anti-slip tape and equipped with safety bars to ensure participant safety.

Experimental Procedure

Each session proceeded as follows: compliance questionnaire, pre-SSQ, grooved pegboard task, three ship warm-up exercise (on projectors, no headset, no motion), first motion profile, mid-SSQ, second motion profile, post-SSQ, grooved pegboard task. The VR/AR and motion conditions were counterbalanced across participants. Because the effects of motion sickness can persist for 24 hours, each session was at least 24 hours apart (M = 10.52 days, SE = 3.29 after excluding two outliers of 184 and 201 days).

All participants gave written consent. A screening and demographics questionnaire was administered at the beginning of each session to ensure subjects were eligible to participate. The preliminary screening asked about any conditions, medications, or activities (e.g., blood or plasma donation within the last 30 days, alcohol consumption, etc.) that might prohibit their participation in the study, and the compliance questionnaire ensured that participants remained eligible for each session. During the second experimental session, participants completed the

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ; Reason & Brand, 1975), which provides an assessment of how likely a person is to experience motion sickness and the types of motion that cause it.

The experimental task consisted of two 15-minute profiles while the participant maneuvered a mock .50 caliber machine gun to destroy hostile ships that approached on the port or starboard side of the participant's ship (~1 per minute). They aimed by moving the grips and pressing where the trigger would normally be located. The butterfly trigger was removed and replaced by a remote control button trigger. During each profile, 15 hostile ships approached, and the participant received firing instructions through the headset. When the ship appeared, the "DESTRUCTIVE FREE FIRE" instruction appeared in red capital letters at the top and bottom of the headset's display (Figure 1). Upon hitting the ship 10 times in the critical region (an unmarked front third of the ship), the "CEASE" instruction appeared in blue capital letters at the bottom of the headset's display (Figure 1). Simultaneously, an explosion would sound from speakers and smoke would billow from the ship. For the VR condition all information about the environment and instructions were contained in the headset (Figure 1). For the AR condition, the environment was projected onto screens (Figure 2), and the instructions were presented through the headset.

Simulator Sickness Assessments

The Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) was administered before the task, between profiles, and after the task. The SSQ measures the severity of current motion sickness symptoms and can be divided into three subscales (Nausea, Oculomotor Discomfort, and Disorientation) or represented as a Total SSQ score. We primarily report data from the Total SSQ score here. This comprehensive score is reflective of overall simulator sickness symptoms without specifying individual symptomology, and larger scores indicate increased simulator sickness symptoms. The Total SSQ score can range from 0 to 236; however, the 50th percentile is 3.7 and the 99th percentile is 75.9 (Kennedy et al., 1993). The grooved pegboard test was administered before and after the shooting tasks were completed. The grooved pegboard test requires the participant to pick up and place pegs one at a time into grooved holes in a pegboard to measure fine motor control. It was included to assess changes in motor control as a result of motion exposure.

Behavioral Measures

Several shooting metrics were collected to identify performance differences between the conditions. Total shots fired was collected and broken down as misses, non-critical region hits, and critical region hits. Overall accuracy was defined as the total number of rounds that hit the hostile ship (in both the critical and non-critical regions) divided by the total number of rounds fired at that ship. Response time from fire command to first shot and cease fire command to last shot, as well as total time to destroy the ship from first shot were recorded.

Results

Simulator Sickness

To examine the impact of headset and motion on simulator sickness, Total SSQ scores were submitted to a 3 (Motion: No Motion, Synchronous Motion, Asynchronous Motion) x 3 (Time of SSQ: Pre, Mid, Post) x 2 (Headset: VR, AR) within-subjects ANOVA. The results, (Table I), showed that only Time of SSQ was significant, $F(2,22) = 4.68$, $p = .020$, $\eta_p^2 = .30$ (Figure 3). This represented a trend for symptoms to increase over time, aligning with other research (Bonnet, Faugliore, Riley, Bardy, & Stoffregen; Stoffregen, Faugliore, Yoshida, Flanagan, & Merhi, 2008; Pettijohn, Geyer, Gomez, Becker, & Biggs, 2018). This serves as a methodological check showing the gentle motion profile used here was capable of eliciting significantly increasing motion sickness symptoms. Average Total SSQ scores are presented in Table II. Total SSQ scores were the most extreme at post-test, so these values were used in correlations with number of shots fired, shots in the critical region, time to destroy ship, response times (RT) to the commence and cease fire commands, and the posttest – pretest difference in grooved pegboard times. None of these correlations reached significance.

Table I. Results of 3 (Motion) x 3 (SSQ Time) x 2 (Headset) ANOVA.

	F	***p***	η_p^2
Motion	1.99	0.160	0.15
SSQ Time	4.68	0.020*	0.30
Headset	0.22	0.648	0.02
Motion x SSQ Time	1.55	0.204	0.12
Motion x Headset	0.12	0.891	0.01
Headset x SSQ Time	1.30	0.292	0.11
Motion x SSQ Time x Headset	1.20	0.327	0.10

* Significant at the $p < .05$ level

Table II. Average Total SSQ Score (standard error) for each condition.

	Headset		
Motion	**Virtual Reality**	**Augmented Reality**	**Average**
No Motion	1.71 (0.24)	1.62 (0.17)	1.66 (0.20)
Synchronous	1.69 (0.17)	1.37 (0.10)	1.53 (0.13)
Asynchronous	1.47 (0.17)	1.54 (0.17)	1.51 (0.16)
	1.62 (0.17)	1.51 (0.14)	

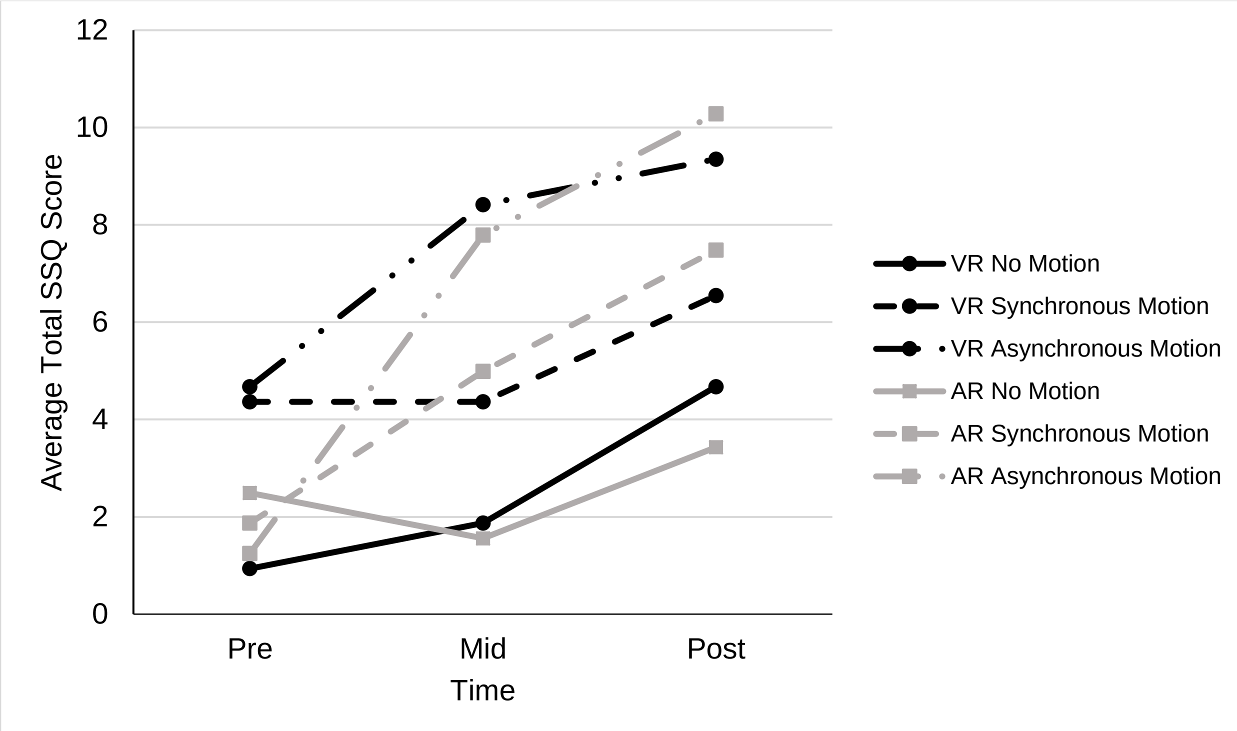

Figure 3. Average Total SSQ Score at each time of administration by headset and motion type.

Behavioral Performance

The shot metrics collected (shots fired, number of rounds on ship, and time to disable ship) are all highly related and showed similar patterns of results. We focused on accuracy, which includes the number of shots fired and the number of shots that hit the target. These data were submitted to a 3 (Motion) x 2 (Headset) ANOVA. The results showed a main effect of Motion, $F(2,22) = 300.15$, $p < .001$, $\eta_p^2 = .97$, and a main effect of Headset, $F(1,11) = 71.36$, $p < .001$, $\eta_p^2 = .87$, such that people were more accurate in the VR (46%) than the AR condition (36%; Table III; Figure 4). The interaction did not reach significance, $F(2,22) = 0.69$, $p = .514$, $\eta_p^2 = .06$. The main effect of Motion showed that people performed better in the No Motion condition compared to the Synchronous and Asynchronous conditions (59% compared to 30% and 34%, respectively; Table III). Bonferroni corrected pairwise comparisons of the motion conditions showed performance was better in the No Motion condition than the Synchronous condition, M_{diff} = 29.1%, p < .001, SE = .019, 95% CI [24.3%, 33.9%] and better in the No Motion condition than the Asynchronous condition, M_{diff} = 25.1%, p < .001, SE = .019, 95% CI [20.2%, 29.9%] . There was no difference between the Synchronous and Asynchronous conditions, M_{diff} = 4.0%, p = .126, SE = .019, 95% CI [-0.8%, 8.9%]. A similar pattern of results can be seen in the number of shots fired in each condition (Table IV). In general, people fired more shots in the AR condition than the VR condition and in the two motion conditions compared to the No Motion condition. It should also be noted that it was possible for a ship to pass by the participant without being disabled; however, this occurred only 26 times out of 2160 events.

Table III. Average accuracy as percentage of total shots that hit the ship (standard error) for each condition.

	Headset		
Motion	**Virtual Reality**	**Augmented Reality**	**Average**
No Motion	64.42	53.55	58.99
	(1.30)	(3.30)	(2.10)
Synchronous	33.82	25.94	29.88
	(1.20)	(1.00)	(1.13)
Asynchronous	39.51	28.34	33.92
	(1.30)	(0.80)	(1.40)
	45.92	35.94	
	(2.41)	(2.36)	

Table IV. Average number of shots fired (standard error) in each condition.

	Headset		
Motion	**Virtual Reality**	**Augmented Reality**	**Average**
No Motion	90.62 (11.30)	99.05 (11.86)	94.83 (8.08)
Synchronous	105.05 (5.95)	160.08 (7.31)	132.56 (7.36)
Asynchronous	89.28 (3.37)	149.89 (5.99)	119.58 (7.16)
	94.98 (4.44)	136.34 (6.67)	

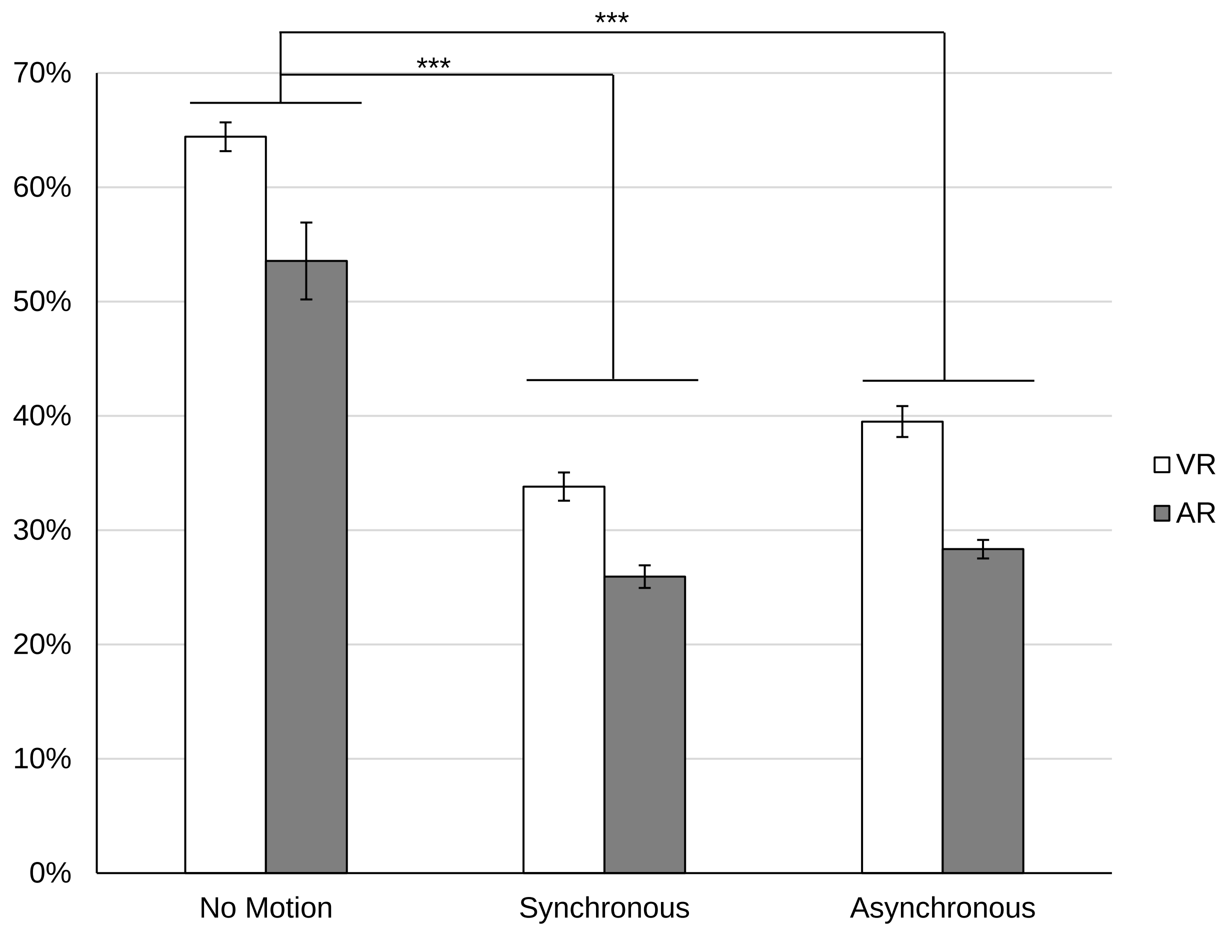

Figure 4. Accuracy (number of shots on target / total number of shots) for each condition. Error bars represent the standard error of the mean. *** Significant at $p < .001$. Main effect of VR/AR at $p < .001$.

There were two main measures of response times: time from FIRE instruction to first shot and time from CEASE instruction to last shot. Time to first shot was submitted to a 3 (Motion) x 2 (Headset) ANOVA. The main effect of Motion was not significant, $F(1,11) = 2.54$, $p = .102$, $\eta_p^2 = .19$. There was a main effect of Headset, $F(1,11) = 6.89$, $p = .024$, $\eta_p^2 = .39$, showing that participants were slower to respond in the VR condition (M = 1.62s, SE = 0.17s) than the AR condition (M = 1.51s, SE = 0.14s;Figure 5). The interaction failed to reach significance, $F(2,22) = 1.21$, $p = .317$, $\eta_p^2 = .10$.

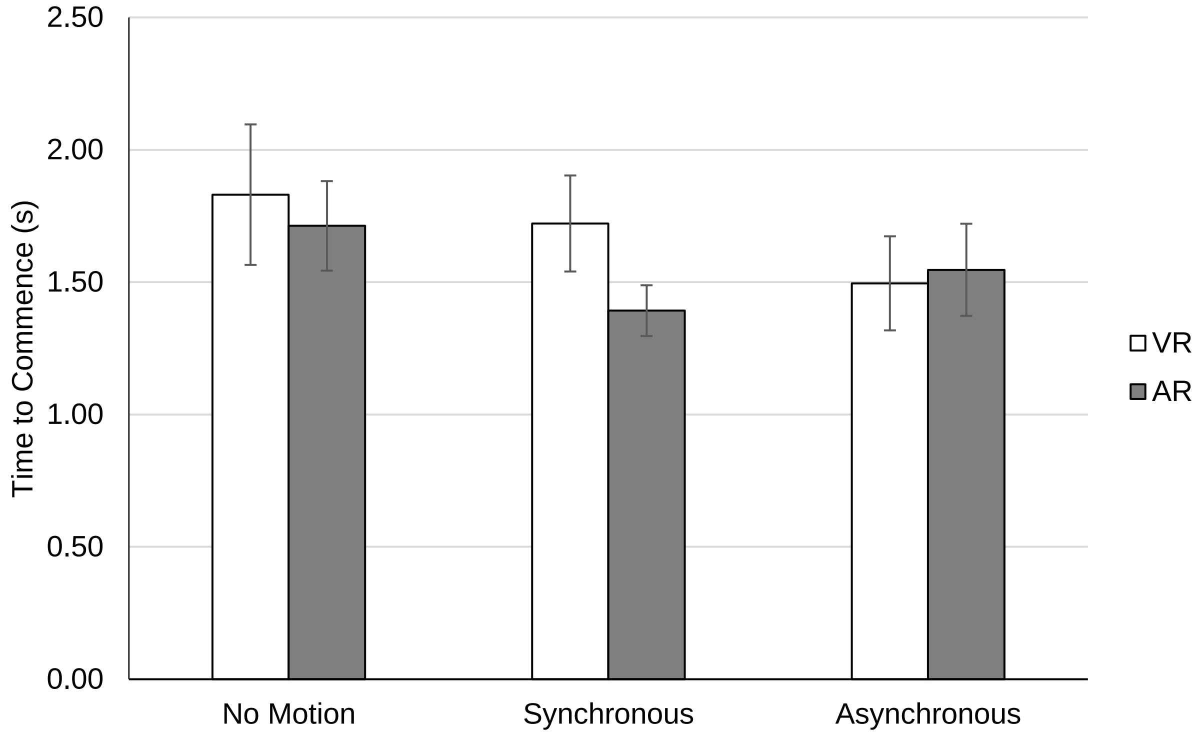

Figure 5. Time between Commence instruction and first shot for each condition. Error bars represent the standard error of the mean. Main effect of VR/AR at $p = .024$.

The time from CEASE to last shot was also submitted to a 3 (Motion) x 2 (Headset) ANOVA. There were no main effects of Motion, $F(1,11) = 0.24$, $p = .786$, $\eta_p^2 = .02$, or Headset, $F(1,11) = 0.09$, $p = .771$, $\eta_p^2 = .01$. The interaction also failed to reach significance, $F(2,22) = 0.12$, $p = .886$, $\eta_p^2 = .01$ (Figure 6). Thus, participants were equally as fast to respond to the CEASE instruction across all conditions.

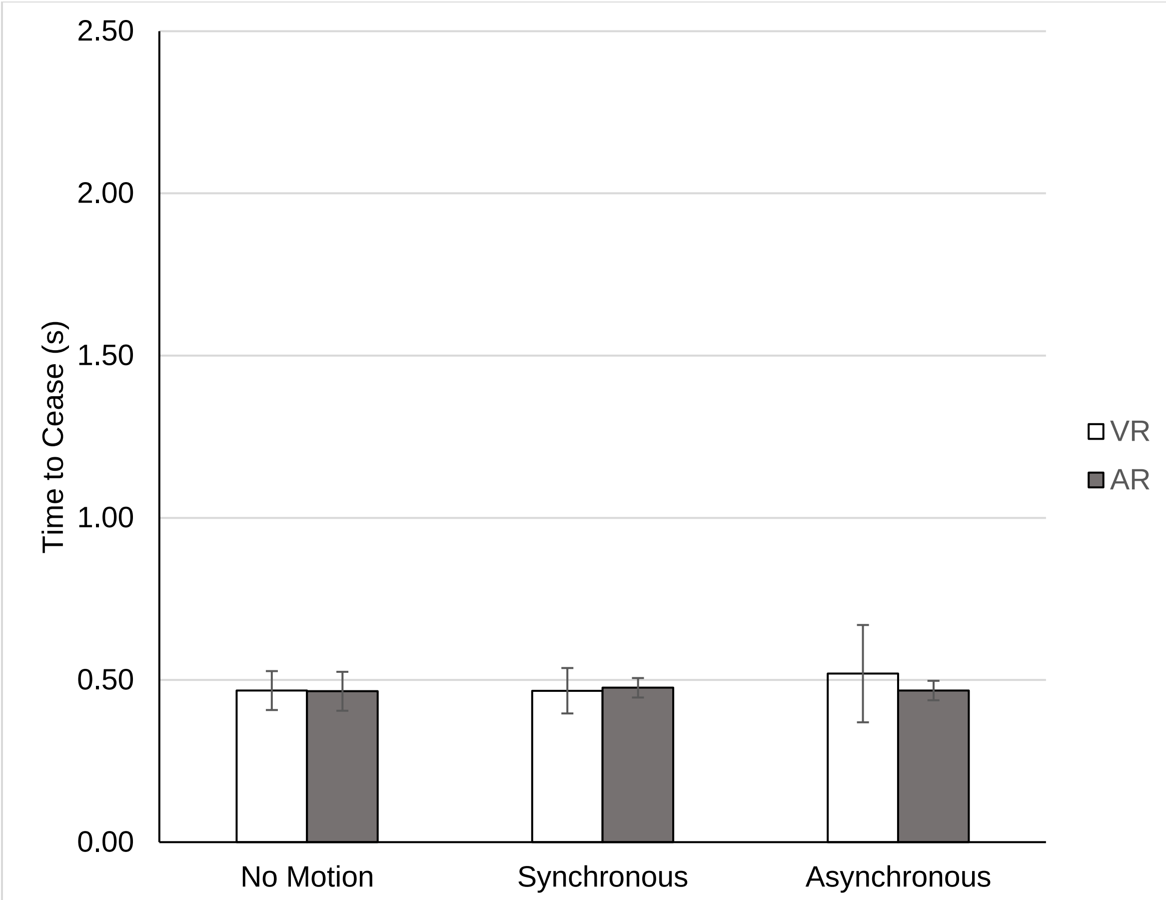

Figure 6. Time between Cease instruction and last shot for each condition. Error bars represent the standard error of the mean.

Discussion

This study examined the effects of VR and AR technologies on simulator sickness and performance under varying motion conditions.

Use of VR and AR increased simulator sickness over time.

There were no significant differences between either technology on sickness symptomology, although overall symptomology significantly increased with time. The main effect of SSQ scores over time is important because it confirms that the combination of technology and the motion profile, which mimicked the motion of an Arleigh-Burke class destroyer on calm seas, was sufficient to evoke simulator sickness. Participants developed symptoms associated with motion in the no motion condition, but neither technology exacerbated symptoms more than the other. It is possible that more prolonged or provocative motion exposure could expose differences between the two systems. Extrapolating from the apparent trend in Figure 3 would suggest that this is the case, with more severe symptoms in the Asynchronous condition.

Motion – both synchronous and asynchronous – did not further induce sickness.

Critically, we manipulated physical motion relative to visual motion because motion synchronicity has significant implications for use of these devices in moving environments. However, there were no significant differences between the No Motion, Synchronous motion, and Asynchronous motion conditions. This evidence suggests that motion asynchrony is not playing a role in exacerbating symptoms under these gentle motion conditions, although it is possible that symptoms may be greatly increased concurrently with asynchrony. Some research has suggested that motion sickness increases with an increase in display lag (DiZio & Lackner, 1997; Jennings, Reid, Craig, & Kruk, 2004; Wildzunas, Barron, & Wiley, 1996). In such cases, the vestibular sense of motion precedes the visual sense of motion as the length of the delay increases. Conflicting studies have found no or weak relationships between display lag and sickness (Draper et al., 2001; Moss, Austin, Salley, Coats, Williams, & Muth, 2011). It should be noted that many of these studies involved seated participants who were moving their heads rather than experiencing externally generated physical motion, and, in at least one case, participants were able to compensate for the lag by slowing their head movements (Draper et al., 2001).

Two studies have researched the question of asynchronous motion more directly. In one, participants flew a flight simulator on land, rode aboard a U.S. Navy Yard Patrol boat, and piloted a flight simulator aboard the Yard Patrol boat. SSQ scores were essentially at floor for all three conditions (Muth & Lawson, 2003). In this study, the sea state ranged from "perfectly flat to a light chop," and the roll of the ship during course changes was the most significant motion captured by an accelerometer. Thus, there was likely little conflict between visual and physical motion. In the second study, people played a driving videogame in a stationary or moving car. Simulator sickness was greater following the motion condition, but no one reached a cut-off criterion (Muth, Walker, & Fiorello, 2006). Additionally, people took longer to perform the driving tasks and were less accurate during the motion condition – similar to what is reported here. The combined evidence from these studies and the current study indicate the need to test the effect of more provocative physical motion. The idea that increased asynchrony could lead to increased sickness will need to be tested further as the evidence here cannot support or refute such a claim. Still, under gentle sea state conditions, motion asynchrony does not seem sufficient to induce symptoms worse than under the No Motion condition.

Motion significantly reduces shot accuracy.

Despite the gentle profiles used here, which mimic the least severe profiles shooters would encounter at sea, introducing physical motion cut accuracy roughly in half. It is also of note that people were no more or less accurate when the motion was uncoupled from the display as in the Asynchronous versus Synchronous motion conditions. This outcome suggests that VR displays may be a viable method of conducting training while the trainee is aboard ship, or at least the lack of synchronized motion will not interfere with training. AR systems may also represent a viable training platform; however, space constraints aboard ship may preclude their use. The equivalent performance between Synchronous and Asynchronous conditions might disappear with more provocative motion, although the current data suggest it is safe to conduct training within mixed reality systems during calm weather conditions. More data is necessary to make claims about conditions with more provocative motion, and individuals with high seasickness susceptibility should remain aware of the potential symptoms that could arise during simulator use.

Shot accuracy was higher in VR compared to AR.

People were more accurate wearing the VR headset compared to the AR headset (see Table III). One explanation is that the VR headset is more immersive, thus people were more engaged with the task. The fact that all visual information was provided by the VR headset, without any peripheral information, may have increased participants' sensory immersion (Ermi & Mäyrä, 2005), leading to more engagement. The degree of immersion may have also been influenced by the experimental setup. Participants stood above the water in the virtual environment, giving the impression that the gunner needs to aim down to hit targets. This was conveyed well through the VR headset but not as well through the projected image seen in the AR condition. As a result, participants had to aim the weapon unusually low to hit the target ships. This may have felt unnatural and decreased the sense of immersion.

There were also differences in response times between VR and AR conditions. If the VR condition were more engaging, participants may have responded more quickly, but the evidence does not support this explanation as participants were faster in the AR condition. This finding would be better supported by a signal salience explanation. Visual scenes are often described in terms of attention as being represented by a salience map, where more salient signals—or signals that stand out in some way—tend to be prioritized and processed faster than less salient signals (Fecteau & Munoz, 2006; Itti, Koch, & Niebur, 1998; Parkhurst, Law, & Niebur, 2002). According to a signal salience explanation, the significant difference to commence fire—and the lack of a significant difference to cease fire—are best explained by the salience of each respective cue as presented in the different platforms. The VR display created a unified visual field that contained all necessary information, yet the cue signal may have lost relative visual prominence because it could blend seamlessly into an image where all components were generated from the same source. Because the AR display blended aspects from multiple sources into a single representation, the commence fire instruction may have stood out more prominently from the seascape. This idea is further supported by a lack of difference for the cease fire instruction, where both VR and AR cease fire cues were supplemented with a highly salient cue—that is, when the hostile ships started spewing smoke. An unambiguous cue at foveal vision is likely to be more salient than a peripheral cue that may or may not blend into the seascape. Thus, the signal salience explanation is supported by having a significant RT difference with cues of potentially unequal salience and no significant difference with a cue of equal salience.

Limitations

Though this study was a controlled experiment, there were some limitations. The largest limitation, as noted throughout the discussion, is the lack of more extreme motion profiles that might have evoked more symptoms, although the primary purpose of this investigation was to assess these symptoms under relatively normal operating conditions. Although there were no significant differences between VR and AR, a larger sample along a normal distribution of symptom endorsement might produce a sub-population with clinically significant impairment in either or both media. Second, the sample size was calculated to detect a medium effect size. If the study had assumed a small effect size, as can be typically assumed for self-reported data, then perhaps a different result could be found. A final limitation of the study is the lack of a positive control that uses the same scale as the SSQ, in order to demonstrate the design was sufficient to detect differences.

Summary

In conclusion, this study represents an important step in examining the differences between VR and AR devices for naval applications. Importantly, the lack of simulator sickness differences between devices and across motion conditions is a promising finding, tentatively suggesting that it is at least feasible to use such devices aboard ship, even when the motion of the virtual ocean does not match the motion of the actual ocean. This is critical given that the use of virtual/augmented environment has the potential to reduce the resources required to purchase expensive devices and travel to remote facilities. Although the current work examined the potential safety issues associated with VR and AR, more work remains to determine the operational and training potential of these mixed reality platforms. However, both platforms appear safe under normal operating conditions at sea.

Key Points

- No differences were found in motion sickness between VR and AR headsets
- Decoupling from visual and physical motion did not exacerbate symptoms
- Accuracy in a computerized shooting task was greatly reduced under motion conditions
- Accuracy was higher in the VR condition
- Response times to the commence fire instructions were faster in the AR condition
- Cue salience may explain the response time differences between the two conditions

References

Bonnet, C. T., Faugliore, E. M., Riley, M. A., Bardy, B. G., & Stoffregen, T. A. (2008). Self-induced motion sickness and body movement during passive restraint. *Ecological Psychology*, *20*(2), 121-145.

Draper, M. H., Viirre, E. S., Furness, T. A., & Gawron, V. J. (2001). Effects of image scale and system time delay on simulator sickness within head-coupled virtual environments. *Human Factors, 43*(1), 129-146.

DiZio, P., & Lackner, J. R. (1997). Circumventing side effects of immersive virtual environments. In M.J. Smith, G. Salvendy, & R. J. Koubek (Eds.), *Advances in Human Factors/Ergonomics. Vol 21: Design of Computing Systems* (pp. 893-897). Amsterdam: Eselvier.

Ermi, L., & Mäyrä, F. (2005). Fundamental components of the game of the gameplay experience: Analysing immersion. In: S. Castell & J. Jensen (Eds.), *Worlds in Play: International Perspectives on Digital Games Research,* vol 37, pp. 37-53. New York, NY: Peter Lang International Academic Publishers.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Fecteau, J. H., & Munoz, D. P. (2006). Salience, relevance, and firing: a priority map for target selection. *Trends in Cognitive Sciences*, *10*(8), 382-390.

Geyer, D. J., & Biggs, A. T. (2018). The persistent issue of simulator sickness in naval aviation training. *Aerospace Medicine and Human Performance, 89(4),* 396-405.

Itti, L., Koch, C., & Niebur, E. (1998). A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on pattern analysis and machine intelligence*, *20*(11), 1254-1259.

Jennings, S., Reid, L. D., Craig, G., & Kruk, R. V. (2004). Time delays in visually coupled systems during flight test and simulation. *Journal of Aircraft, 41*(6), 1327-1335.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An advanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

Lawson, B. D. (2014). Motion sickness symptomatology and origins. In: K. S. Hale & K. M. Stanney (Eds.), *Handbook of Virtual Environments: Design, Implementation, and Applications. 2nd ed.* (pp. 531-600). New York, NY: CRC Press.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.

Moss, J. D., Austin, J., Salley, J., Coats, J., Williams, K., & Muth, E. R. (2011). The effects of display on simulator sickness. *Displays, 32*(4), 159-168.

Muth, E. R., & Lawson, B. (2003). Using flight simulators aboard ships: Human side effects of an optimal scenario with smooth seas. *Aviation, Space, and Environmental Medicine, 74*(5), 497-505.

Parkhurst, D., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual attention. *Vision Research*, *42*(1), 107-123.

Patterson, R., Winterbottom, M. D., & Pierce, B. J. (2006). Perceptual issues in the use of head-mounted visual displays. *Human Factors, 48*(3), 555-573.

Pettijohn, K. A., Geyer, D., Gomez, J., Becker, W. J., & Biggs, A. T. (2018). Postural instability and simulator seasickness. *Aerospace Medicine and Human Performance*, *89*(7), 634-641.

Stoffregen, T. A., Faugliore, E. M., Yoshida, K., Flanagan, M. B., Merhi, O. (2008). Motion sickness and postural sway in video games. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50*(2), 322-331.

Wildzunas, R. M., Barron, T. L., & Wiley, R. W. (1996). Visual display effects on pilot performance. *Aviation, Space, and Environmental Medicine*, *67*(3), 214-221.